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PROSPECTS FOR INERTIAL FUSION ENERGY BASED ON A DIODE-PUMPED SOLID-STATE LASER (DPSSL) DRIVER: OVERVIEW AND DEVELOPMENT PATH

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With the ever-present demand for electrical power in the modern world, the technical community must prepare a development path for a technology that will be able to meet future energy demands within appropriate cost guidelines. We are exploring whether inertial fusion energy (IFE), as one option among those having an essentially inexhaustible fuel source, can have an acceptable technological risk and sufficiently low environmental impact to be a practical solution. In inertial fusion, a “fuel” of hydrogen isotopes such as deuterium and tritium are compressed (imploded) to 100 million degrees and a density nearly a thousand times liquid hydrogen densities, and then “confined” by its own inward-moving inertia so that the nuclei fuse together to make helium and fast neutrons—hence the name of the process—inertial confinement fusion (ICF). In such a very short-pulse event, a small amount of mass is converted to energy ($E = mc^2$), and this energy can be collected as heat in a fusion chamber to operate a power plant with a steam turbine in much the same way as a coal-fired plant. A fusion plant, however, needs a driver to generate beams of energy to compress the fusion fuel to the required conditions.

We are concerned in this paper with the one type of driver that appears to be prepared to support the IFE mission—a diode-pumped solid-state laser (DPSSL). This type of laser is similar to a flashlamp-pumped laser, except that it uses light-emitting laser diodes instead of flashlamps, and special crystals instead of the usual Nd-doped glass. These substitutions are needed for rep-ratable operation.

A DPSSL has now become a credible choice for an IFE driver for the following reasons:

1. Inertial fusion is *known* to work with sufficient energy input. Underground experimental tests in Nevada have allowed the demonstration of excellent performance, putting to rest the fundamental questions about the basic feasibility of achieving high gain.
2. We have published (1) a comprehensive conceptualization of a DPSSL-driven IFE power plant based on a full systems analysis. This analysis was possible only because of recent advances at the Lawrence Livermore National Laboratory (LLNL) in the growth of a new crystal laser gain medium (Yb:S-FAP), the fabrication of efficient laser diodes to pump this gain medium, and the development of thermal-management techniques to cool these new crystals. This study proves that a DPSSL-driven IFE plant is possible, given the required development.
3. A DPSSL is related to existing solid-state lasers, in terms of its basic architecture and optical components, other than the gain medium and pumping optics. The experimental success for a DPSSL can therefore draw from the significant experimental base established with these existing solid-state Nd-glass lasers such as Omega at the University of Rochester and Nova at LLNL, where laser beams have successfully imploded fusion capsules. This means that, in essence, target physics and laser operation have already been investigated to a considerable degree for a DPSSL.

4. A DPSSL is the natural continuation of the solid-state-laser technology being developed for the National Ignition Facility (NIF) being built at LLNL. One mission of the NIF is to provide the proof of principle for the target physics *at small enough scale* to ensure competitive IFE economics. When the NIF accomplishes this mission, the results will also apply to a DPSSL driver—but for single-shot, not repetitive, operation.
5. Project Mercury, just under way at LLNL, will prove that a DPSSL can be rep-rated at 10 times per second, thus demonstrating that a DPSSL can achieve the required performance, based on a certain level of scaling from the specifications for Mercury to those for an IFE system. The proof of such scaling requires further development.

Project Mercury is a three-year project at LLNL to design (FY97), build (FY98), and operate (FY99) a 100-joule 10-Hz DPSSL that is compatible with scaling to >1 kilojoule in future single-arm systems, and eventually to IFE systems at the megajoule scale. The goals include an overall electrical efficiency of ≥10%, a final focus less than 5 times the size of a diffraction-limited beam, and pulse lengths of 1 to 10 ns. What this means is that the Mercury laser will demonstrate the utility of a DPSSL as an IFE power plant driver in many respects, but not in total energy output—it will demonstrate the relevant pulse duration, the needed laser efficiency, and the required thermal management at a repetition rate of 10 times every second. It is important to note that the efficiency of interest for an IFE driver is the total efficiency in driving a fuel capsule, which should be ≥10% (actually, it is the product of the efficiency and the capsule gain that should be ≥10). This means that the efficiency must include the efficiency factor for the coupling of the beam energy to the fusion capsule. Such a factor, which depends on the quality and lateral spread of the beams at the target, is about 90% for a DPSSL, based on experiments at Nova and at other laser facilities.

The remaining issues that still need to be addressed for DPSSLs can be addressed over time through a development path such as the following:

1. Project Mercury, with phased operations from 1999 through the year 2003.
2. The NIF, with Nd-glass operation beginning about 2002, and extending for perhaps 20 years.
3. Project Venus: a one-kilojoule single-arm DPSSL beam line.
4. Project Terra: a 30-kilojoule single-arm DPSSL beam line.
5. A full DPSSL facility providing several megajoules of energy.
6. A complete engineering demonstration facility, leading to an operating DPSSL-driven power plant.

In many respects, it appears that the interest in a DPSSL driver is growing steadily. The main inhibiting factor so far has been the cost of the laser diodes, but that is expected to drop as the market for laser diodes expands. With the experimental base behind it, and Project Mercury to demonstrate the rep-ratable characteristics of the new crystal gain media, it would appear that DPSSLs are indeed a viable candidate for an IFE power plant to supply the future energy needs of mankind.

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References

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